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CAPE COD EASTERLY SHORE BEACH EROSION STUDY. VOLUME I. MAIN REP--ETC(U)
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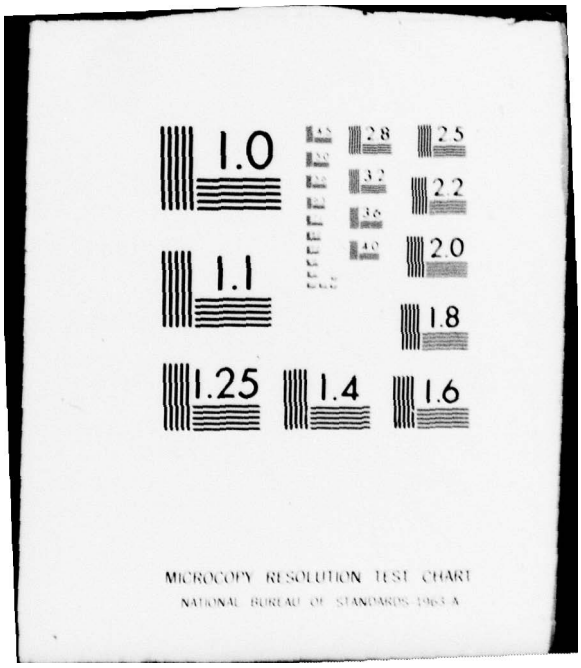
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CAPE COD EASTERLY SHORE BEACH EROSION STUDY

VOLUME I
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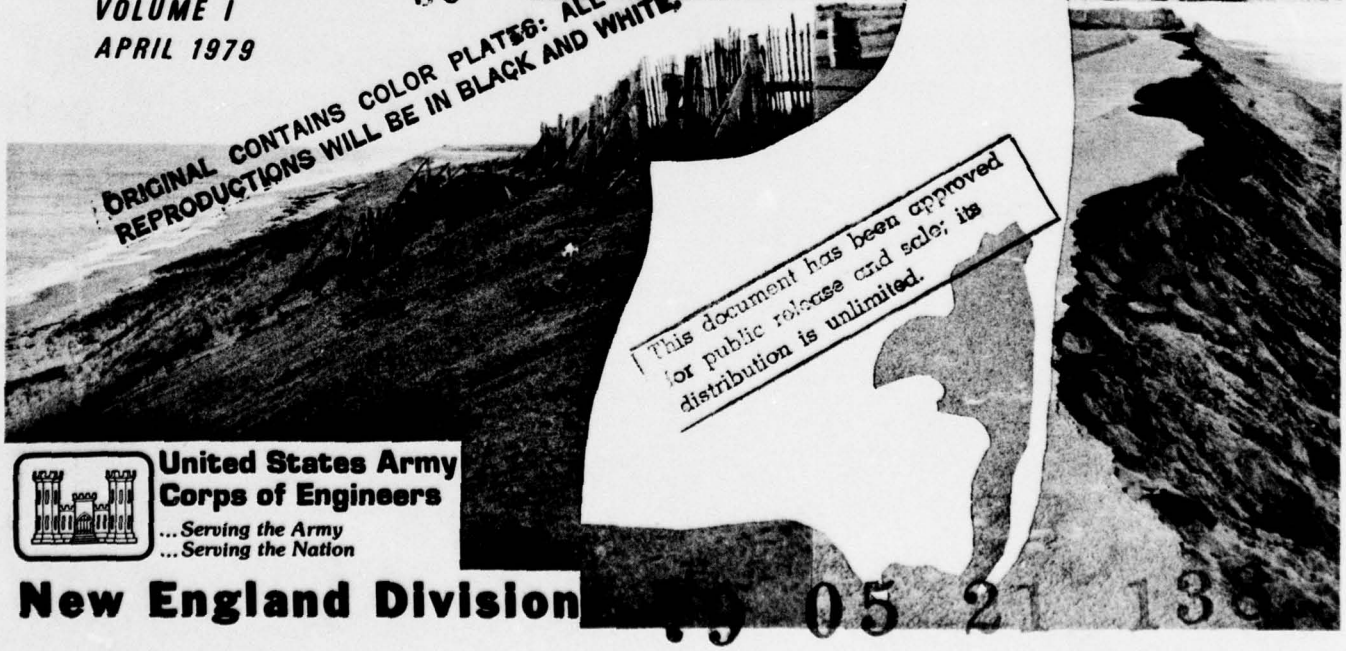

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New England Division

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: (14) 39-54-VOL-1
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): (6) Cape Cod Easterly Shore Beach Erosion Study, Volume I. Main Report.
5. TYPE OF REPORT & PERIOD COVERED: Beach Erosion, Early History to 2029
6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): U. S. Army Corps of Engineers New England Division Waltham, MA 01254
8. CONTRACT OR GRANT NUMBER(s): (15) DACW 33-78-C-0022

9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Corps of Engineers / New England Div. (NEDPL-C) / Waltham, MA 02154 / Analysis & Technology, Inc / P O Box 2200 / No. Stonington, CT 06359
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Congressional Authorization 12/2/70

11. CONTROLLING OFFICE NAME AND ADDRESS: (11) Colonel John P. Chandler, Colonel, Corps of Engineers, New England Division Waltham, MA 02154
12. REPORT DATE: April 1979
13. NUMBER OF PAGES: 3 vol. I-49 II-101 III-437

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (12) 58p.
15. SECURITY CLASS. (of this report)
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(9) Final rept.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Historical research, Reconnaissance Reports, Erosion problems, Hydrology Analysis, Planning coordination

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report is designed to encourage the National Park Service and locals to improve their beaches using non-structual methods. The report is divided into 3 volumes- Vol. I-main report, Vol. II Technical report, Vol. III Reconnaissance reports. Vol.I discussed the study area in general with recommendations and conclusions. Vol.II discussed in detail the erosion and accretion causing elements. Vol.III- individual town and National Park Service reconnaissance reports describing each area, discussing the problems and suggesting solutions.

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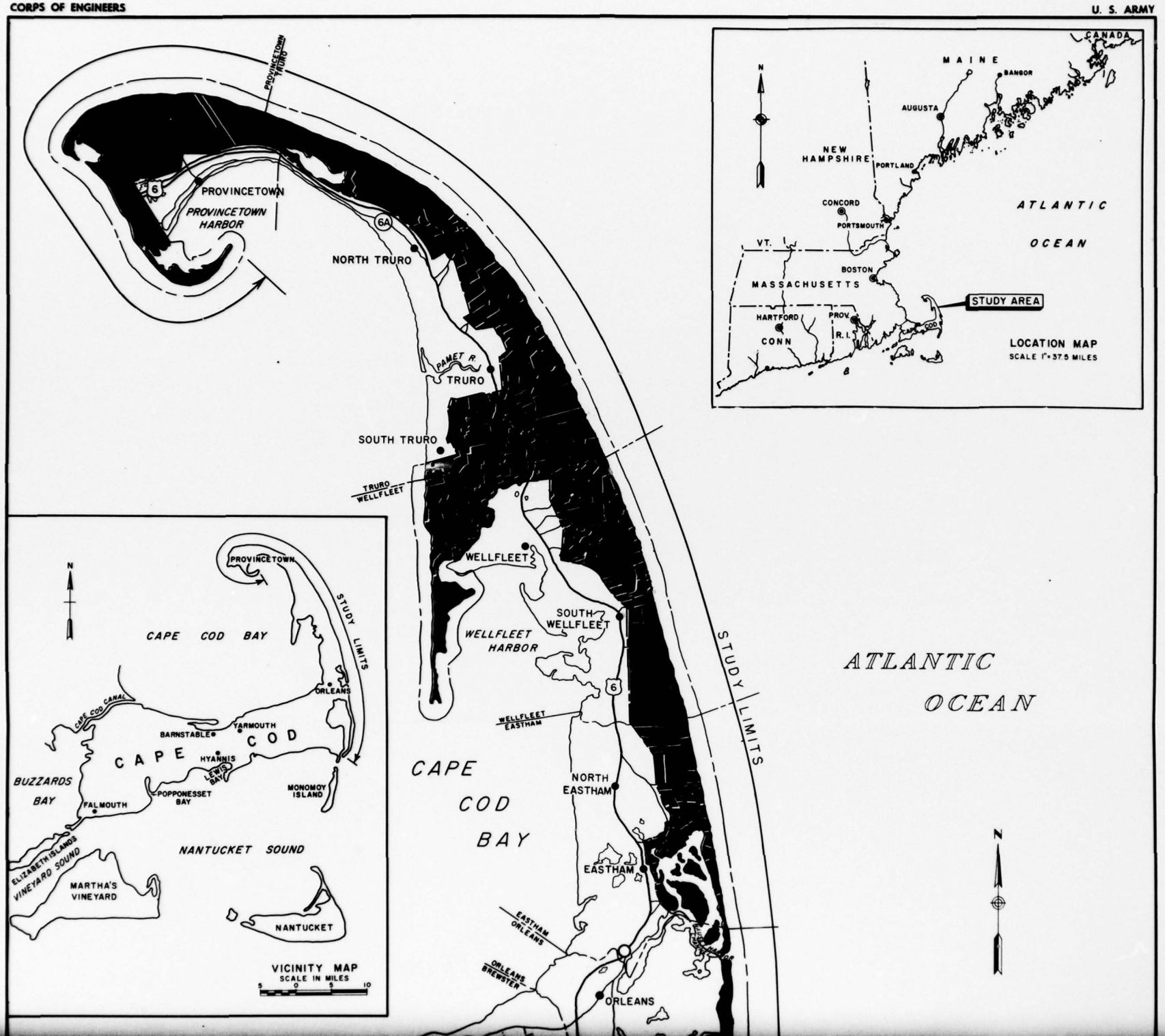
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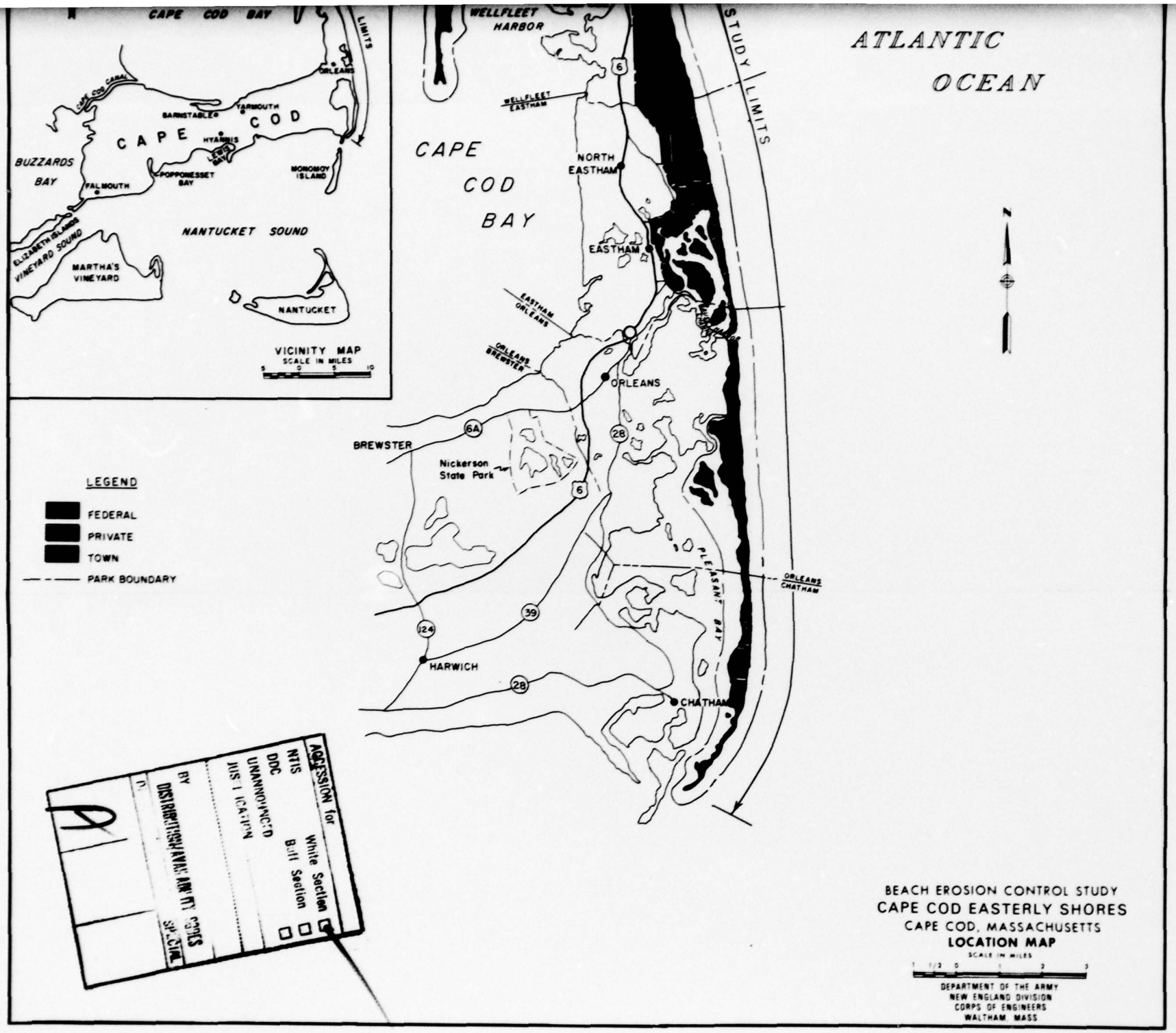

BEACH EROSION CONTROL STUDY
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DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM MASS

PLATE 1

SYLLABUS

This beach erosion control study was made to survey the easterly shores of the outer arm of Cape Cod, Massachusetts, extending approximately 46 miles from Long Point in Provincetown to the southern tip of Nauset Beach in the interest of beach erosion control, hurricane protection and allied purposes.

The principal problem along this shore is the erosion and recession of the shoreline resulting in the loss of protective and recreational beach areas and the exposure of backshore dunes, parking areas, roads and structures as a result of frequent northeast storms. Although hurricane force winds and tidal flooding do cause severe damage when they occur, they are not the cause of the majority of the problems in the area. The purpose of this study is to determine whether an economical, technical or environmentally feasible plan of protection for the study area can be provided.

Cape Cod's coast is eroding along most of its easterly shore. The following methods of erosion control were considered; 1) Rock Revetment, 2) Nearshore Stone Mound, 3) Offshore Stone Breakwater, 4) Precast Concrete Mound, 5) Stone Groins, 6) Stone Groins with Sandfill, 7) Sandfill, 8) Dune Restoration. Costs ranged from $981,000 to $36,428,000. The cost of each plan was compared to the benefits and environmental impacts derived from the plan. None of the protective measures considered met the necessary economic requirements for federal participation in the cost of their construction.

Due to this lack of economic justification, it is recommended that no beach erosion control project be adopted by the United States for providing protection against erosion and storm damage along the easterly shore of Cape Cod.

It is further recommended that local interests plan to implement, as soon as possible, the non-structural measures which have been suggested and discussed in this report.

INTRODUCTION

The Corps of Engineers has been directed to make a survey of the easterly shores of the outer arm of Cape Cod, Massachusetts, extending from Provincetown to the southern extremity of Nauset Beach in the interest of beach erosion control, hurricane protection and allied purposes. The survey was authorized by a resolution adopted by the Committee on Public Works of the House of Representatives on 2 December 1970. The report is divided into three volumes: Volume I, Main Report; Volume II, Technical Report; and Volume III, Reconnaissance Report.

Although the Corps was unable to justify financial participation in shore protection along the easterly shore, we have tried to compile background information, both technical and non-technical. The above-mentioned volumes and discussions are designed to assist other federal agencies and state and local interests in future development and management of the Cape Cod easterly shore. The recommendations suggested in this report are for consideration by individual towns and by the National Park Service to assist them in retarding the erosion along the shore.

ACKNOWLEDGMENTS

This report was made under the direction of:

John P. Chandler, Colonel, Corps of Engineers, Division Engineer

Joseph L. Ignazio, Chief, Planning Division

It was completed under the supervision of Mr. Oscar Arpin, former Chief, Coastal Development Branch; Mr. Donald Martin, Chief, Coastal Development Branch. Mr. Thomas C. Bruha, Project Manager, developed the report and Analysis & Technology, Inc., of North Stonington, Connecticut, researched pertinent data, summarized and evaluated technical information and prepared the final report.

CAPE COD EASTERLY SHORE BEACH EROSION CONTROL STUDY MAIN REPORT

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MAIN REPORT

THE STUDY AND REPORT

Cape Cod's heritage has long been tied to the sea. Provincetown was the original landfall for the Pilgrims on the Mayflower. Fishing, whaling and maritime commerce have all been important parts of the Cape's history. Cape Cod's dependence on the sea for its livelihood continues today as the natural beauty of the Cape's coast draws numerous visitors seeking recreation such as: swimming, boating, fishing, shellfishing and sunbathing. The sea has also been responsible for shaping the Cape into the outline so familiar to all. This work continues today as storms, winds, waves, tides and currents have caused erosion of the great marine cliff on the Cape's Atlantic coast, retreat of the barrier beaches and accretion on the northern coast of Provincetown. Structures at the top of the scarp have been destroyed or moved as erosion has undermined the scarp face. Beaches and beach facilities have been seriously damaged, property has been lost and navigation through inlets to harbors has become hazardous.

PURPOSE AND AUTHORITY

Recognizing the above mentioned problems, the associated environmental matters and in response to concern about erosion problems expressed by local interests through their representative in Congress, the Committee on Public Works of the United States House of Representatives adopted the following resolution on 2 December 1970:

> Resolved by the Committee on Public Works of the House of Representatives, United States that, in accordance with Section 110 of the River and Harbor Act of 1962, the Secretary of the Army is hereby requested to direct the Chief of Engineers to make a survey of the easterly shores of the outer arm of Cape Cod, Massachusetts, extending from Provincetown to the southern extremity of Nauset Beach, in the interest of beach erosion control, hurricane protection and allied purposes.

SCOPE OF THE STUDY

The study involves the easterly shore of Cape Cod from Long Point at Provincetown to the southern tip of Nauset Beach, Chatham, about 46 miles of shoreline all within the boundary of the Cape Cod National Seashore. The area is contained within the towns of Provincetown, Truro, Wellfleet, Eastham, Orleans and Chatham. The shoreline is made up of dunes, bluffs and beaches consisting of unconsolidated glacial material that is easily eroded by the storm-driven waves frequently experienced during easterly storms.

Because of the impact of continued erosion on Cape Cod and the Cape Cod National Seashore, this study was initiated to determine the historical erosion rate based on available scientific surveys and studies and to project the shoreline changes anticipated during the next 50 years. Historical charts, aerial photographs and scientific investigations were studied; a wave refraction analysis for the Cape's outer shores was performed; the geology and hydrology of the area were investigated; and economic factors and land use at the present time were determined and projections for the next 50 years were made. Plans to reduce the erosion rate on Cape Cod's Atlantic coast were considered, and the economic justification for implementing these protective measures was studied.

STUDY PARTICIPANTS AND COORDINATION

On 28 November 1973 a public meeting was held to exchange information about the study, beach erosion and related problems, and possible solutions. Views of people living in the area concerning erosion and the study were solicited. A summary of the comments generated during the public meeting is presented in Appendix 4 of Volume II. A brief discussion concerning additional meetings held with officials from each of the towns in the project area, representatives of the National Park Service, and federal, state and local fish and wildlife personnel is also included in Appendix 4 of Volume II.

Federal, state and local agencies with an interest in the easterly shores of Cape Cod were contacted during the study. Their views are presented below and in Appendix 4 of Volume II.

Figure 1. Coast Guard Beach, Eastham, Massachusetts, 1965

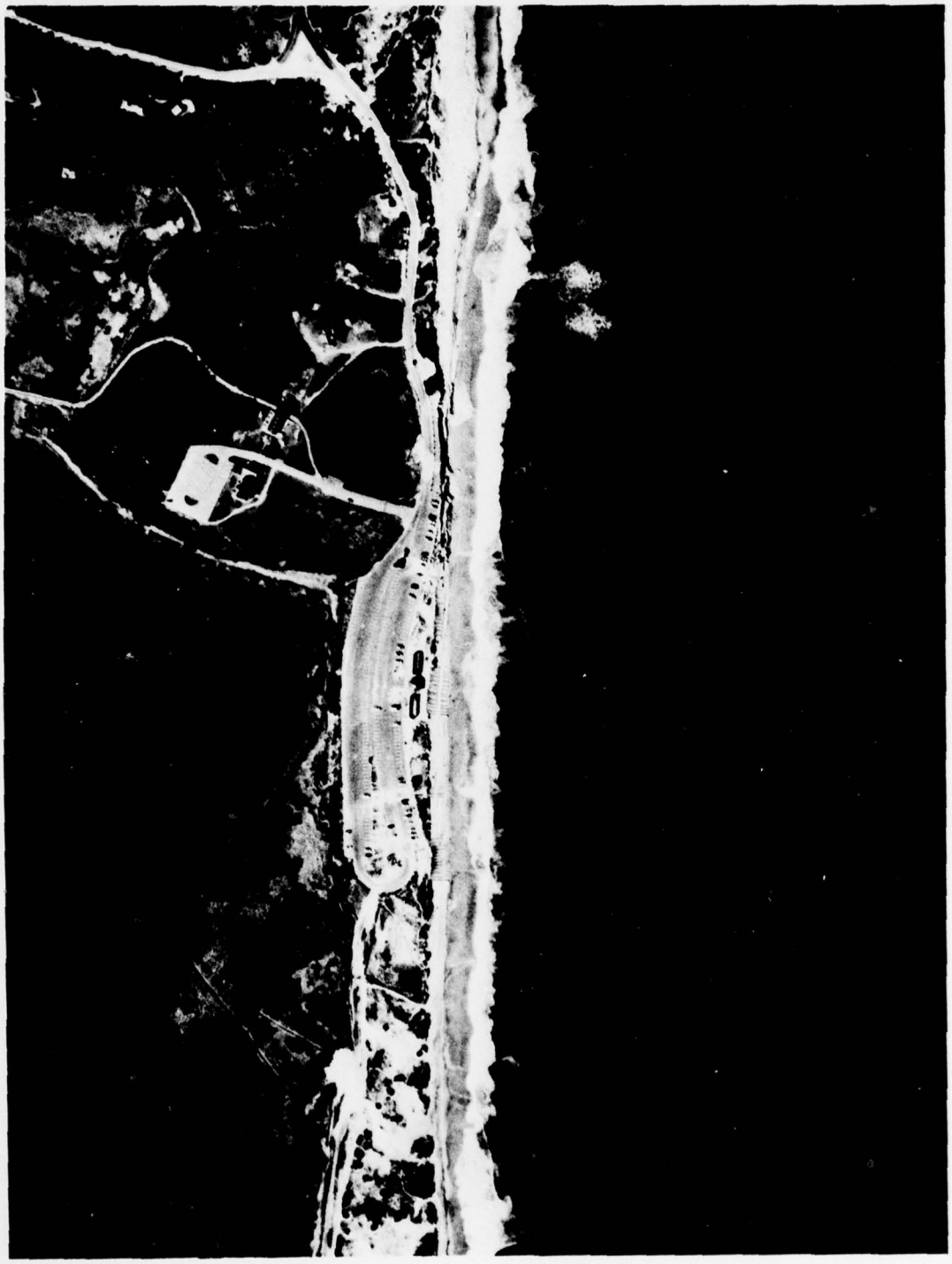

Figure 2. Coast Guard Beach, Eastham, Massachusetts, 1977

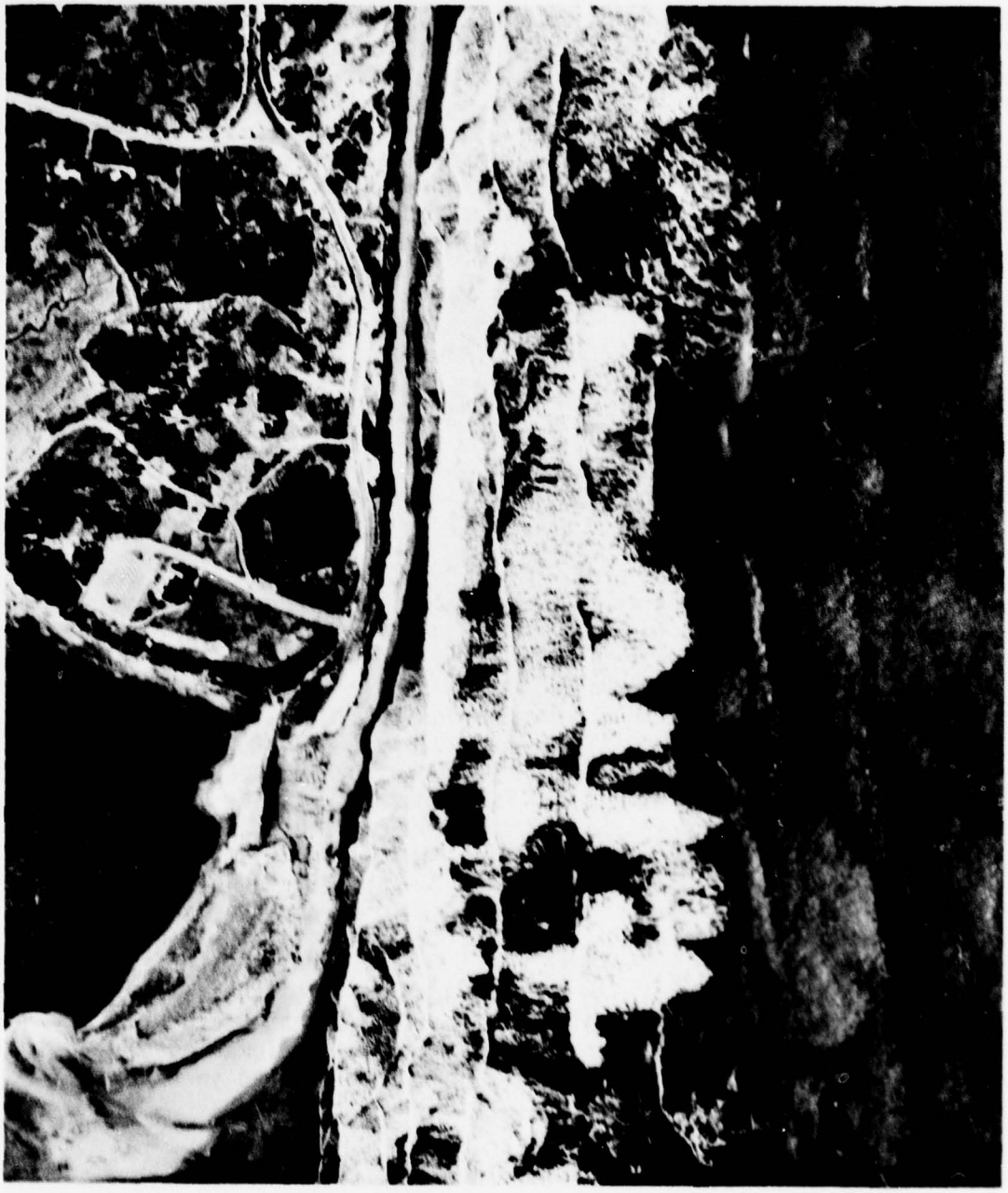

Figure 3. Coast Guard Beach, Eastham, Massachusetts, 1978

THE REPORT

In the interest of clarity, brevity and ease of reading, this report is divided into three volumes. Volume I is the main report consisting of a description of the study area, a discussion of the problems and plans formulated to deal with the problems, and an economic analysis of any considered improvements. Technical analyses of shore processes and the factors affecting them, and the geology, hydrology, shore history, littoral processes and economy of the study area are presented in Volume II. A detailed description of the considered plans of improvements, their economic justification and the views of individuals, organizations and agencies are also included in Volume II. Volume III consists of individual reconnaissance reports for the National Park Service beaches and each of the six towns in the project area. Shoreline changes near military installations, Nauset Harbor and Old Harbor are discussed.

PRIOR STUDIES AND REPORTS

Survey reports for Pleasant Bay, in the towns of Orleans, Harwich and Chatham, and Nauset Harbor in the towns of Eastham and Orleans, and a cooperative beach erosion control study which included a part of Provincetown have been completed by the New England Division of the U.S. Army Corps of Engineers. The Pleasant Bay study submitted in November 1968 proposed a stabilized inlet through Nauset Beach connecting Chatham Harbor and the Atlantic Ocean, a navigation channel through the inlet, closure of the existing inlet with a sand dike, a channel connecting Chatham Harbor with Nantucket Sound and channels connecting Chatham Harbor and Pleasant Bay with the adjoining coves. An adequate economic justification for the project existed, but the local contribution required was prohibitive. The Nauset Harbor study, submitted in June 1969, considered a plan that included a stabilized inlet through Nauset Beach, a navigation channel through the inlet and branch channels in adjacent areas and anchorages. However, the benefits resulting from implementation of the plan were found to be insufficient to justify the work. The beach erosion control study for Provincetown discussed Provincetown Beach (now Herring Cove Beach). It recommended that beach widening, groins and a concrete seawall along the backshore be implemented by non-federal interests. To date, the Corps has not participated in work done on the beach.

Figure 4. Oblique view of Nauset Harbor and connecting waterways, Cape Cod, Massachusetts

Figure 5. Oblique view of Pleasant Bay and connecting waterways, Cape Cod, Massachusetts

RESOURCES AND ECONOMY OF THE STUDY AREA

Cape Cod's natural resources are the source of its popularity and the lifeblood of its economy. The outer Cape consists largely of forests, agricultural and open lands and wetlands. Only a small portion is used for commercial centers and residential development.

Th Cape's economy is dependent on the tourist industry, and most employment is centered in services and in wholesale and retail trade. Cape Cod has attracted a growing number of year-round residents (particularly retirees), summer residents and visitors who stay for one day, several days or weeks.

At present, the beaches are under-utilized due to lack of adequate access from metropolitan areas and lack of parking facilities (see Volume II, Appendix 3). Erosion has damaged the few existing facilities and complicated any plans for adding more.

NATURAL RESOURCES

Cape Cod's easterly shores all lie within the bounds of the Cape Cod National Seashore. The northern Cape beaches are usually backed by grass-covered sand dunes. Generally, a high scarp is located behind the beaches in the middle of the outer Cape. Most of the southern section consists of Nauset Beach, a long barrier beach-spit complex that protects Nauset Harbor and Bay, Chatham Harbor and Pleasant Bay from the open Atlantic. Nauset Harbor, a large, natural tidal lagoon that is used extensively for recreational boating, is popular for fishing and shellfishing. Pleasant Bay, another saltwater lagoon, and Chatham Harbor are also popular boating and fishing areas, and Pleasant and Little Pleasant bays are rich in shellfish.

Provincetown consists of a densely populated commercial area along the harbor surrounded by a large, undeveloped area that is part of the National Seashore Park. Truro and Eastham are rural; any development is largely residential, with business development generally occurring along the highway. Wellfleet has a pleasant commercial area, a large harbor and much undeveloped land, while Orleans is the local center of commerce. Chatham, with the largest year-round population on the outer Cape, has an attractive, densely populated town center.

HUMAN RESOURCES

In 1970, the population of the United States exceeded 200 million people. One-third of this populace lives within a day's drive of Cape Cod. Residents of Massachusetts and the neighboring states of Connecticut, New York and New Jersey constitute about 75 percent of the visitors to the Cape.

Cape Cod's year-round population of 128,000 nearly triples in the summer. About 21,000 of the year-round residents (1975) live on the outer Cape, and in summer the population there increases to about 90,000. It is projected that the year-round population on the outer Cape will grow to about 31,000 by 1995 and to about 50,000 by the year 2027. Summer population there is expected to reach 123,000 by 1995 and 143,000 by 2027. The Cape's population has been growing at a faster rate than that of the United States and the rest of Massachusetts. Recent increases reflect in part the growing attraction of Cape Cod for people seeking a place for retirement; about 25 percent of the Cape's year-round residents are senior citizens.

DEVELOPMENT AND ECONOMY

Cape Cod's rural atmosphere has attracted people seeking retirement homes and second homes, vacation and recreational opportunities. The large summer population includes families with second homes and visitors who stay several days or weeks. Preserving the natural environment that attracts people to Cape Cod is vital to the Cape's continued popularity.

In 1971, more than 80 percent of the outer Cape was covered by forest, agricultural or open lands and wetlands. As development continues, more open land will gradually be converted to residential, with some growth anticipated in commercial areas. Because of conservancy measures adopted by the towns and land use regulations of the Cape Cod National Seashore, more than 60 percent of the land area on the outer Cape will experience no further commercial or residential development. Environmental considerations that may inhibit future development include the availability of adequate pure water, the capacity of the soil for septic disposal and the availability of undeveloped land. Provincetown has already reached saturation and, with the exception of Truro, the other outer Cape towns should experience land saturation within the next 50 years. (For further details see Appendix 1 of Volume II.)

Continued development may produce a conflict between preserving the Cape's environment and providing a stimulus for the local economies because economic growth is tied to development. The economy is dependent on tourism, which accounts for about 85 percent of summer payrolls. Employment is highest in the wholesale and retail trades, followed by services and construction. The seasonal trend in business leads to high winter unemployment rates ranging from almost 46 percent in Provincetown to 9 percent in Truro. The unemployment rate for the entire Cape increases from 8.5 percent in August to almost 18 percent in February. Manufacturing, transportation, communications, utilities, finance, insurance, real estate, agriculture, forestry and fisheries constitute only 17 percent of the average employment on the outer Cape. (See Appendix 1 of Volume II for details.)

PROBLEMS AND NEEDS

This report is designed to address the problems and needs of the erosion of Cape Cod's easterly shores caused by natural forces such as waves, wind and storms and accelerated by man's impact. These issues as well as considered plans of improvement to alleviate these problems are discussed on subsequent pages of this report.

DESCRIPTION

Cape Cod (Barnstable County) is the easternmost part of the Commonwealth of Massachusetts. In outline, the Cape resembles a flexed arm. The easterly shores of Cape Cod, which span 46 miles in the towns of Provincetown, Truro, Wellfleet, Eastham, Orleans and Chatham, are included in the Cape Cod National Seashore boundaries.

Cape Cod consists primarily of unconsolidated sands and gravels that are easily eroded, particularly by the winds, waves, tides, currents and storms that occur along the Atlantic coast. Erosion has produced a high scarp along the Cape's eastern shores from Truro to Eastham, and the material eroded from the scarp has been transported to the north and south. In the north, Provincetown's coast has grown seaward, while in the south, barrier beaches have been built, creating inlets, saltwater lagoons and protected bays and marshes.

Sandy beaches stretch along the easterly shores of Cape Cod from Long Point in Provincetown to the tip of Nauset Beach in Chatham with only two interruptions - Hatches Harbor in Provincetown and Nauset Harbor in Eastham and Orleans. Hatches Harbor is a large, shallow tidal marsh located behind Race Point. Nauset Harbor is a large, tidal lagoon used extensively for recreational boating and sport fishing. At the extreme southern end of the study area, the inlet to Chatham Harbor provides access from the Atlantic to Chatham Harbor and then to Pleasant Bay, another large tidal lagoon popular for boating and fishing.

Beaches from Long Point to Race Point on Provincetown's western shore are located on Cape Cod Bay, and beaches on the eastern shore of Cape Cod face the Atlantic Ocean. On the Provincetown coast and in northern Truro the beaches are generally backed by grass-covered dunes. From North Truro to Coast Guard Beach in Eastham, the beaches are located at the base of a high scarp that climbs more than 150 feet in some locations. Barrier beaches reach south from Coast Guard Beach, sheltering Nauset Harbor, Chatham Harbor and Pleasant Bay.

Development along the coast has been minimal, except for seasonal cottages, navigational aids and beach facilities located close to the shore. Future development near the beaches is regulated by the National Park Service because the land is within the boundaries of the Cape Cod National Seashore.

The study area is shown on National Ocean Survey Chart 13246 and on the U.S. Geological Survey topographic maps for the Chatham, Orleans, Wellfleet, North Truro and Provincetown quadrangles. Geologic maps are available for the Chatham, Orleans, Wellfleet and North Truro quadrangles.

STATEMENT OF THE PROBLEM

The problems on Cape Cod's easterly shores are the erosion of the scarp, recession of the shoreline and landward migration of the barrier beaches as a result of severe northeast storms and the careless habits of man. Structures at the top of the scarp have been destroyed or moved and property has been lost as erosion has undermined the scarp face. Beaches and beach facilities have been seriously damaged by washover processes on barrier beaches. Inlets to Nauset Harbor and Chatham Harbor are unstable making navigation hazardous, and the inlet locations change as barrier spit configurations change.

Erosion has been occurring on the western shore of Provincetown and it has been particularly severe along the scarp from northern Truro to Eastham. The barrier beaches from Eastham to the tip of Nauset Beach are eroding on the seaward side and generally accreting on the bay side. Provincetown's northern coast is accreting rather than eroding, and some of the sand deposited on the beaches is blown inland. Windblown sand causes problems for motorists; migrating dunes encroach on the highway and, in the past, on Provincetown itself. Deposition of sand is also a problem at the inlets to Nauset and Chatham harbors, where it is difficult to chart and maintain navigation channels.

FACTORS PERTINENT TO THE PROBLEM

Cape Cod has been formed and changed by many interacting forces, some of which are still at work today. These forces are discussed in the following sections.

a. Geomorphology

During the Ice Age, ice sheets moved southward from Canada and covered the area where Cape Cod is today. These glaciers carried clay, silt, sand, gravel and even large boulders which were deposited to form the Cape. The outer Cape from Truro south consists primarily of sand and gravel deposited by meltwater streams draining the glacier. In addition to these outwash plains, some material deposited at the glacial margin is found in the Orleans area.

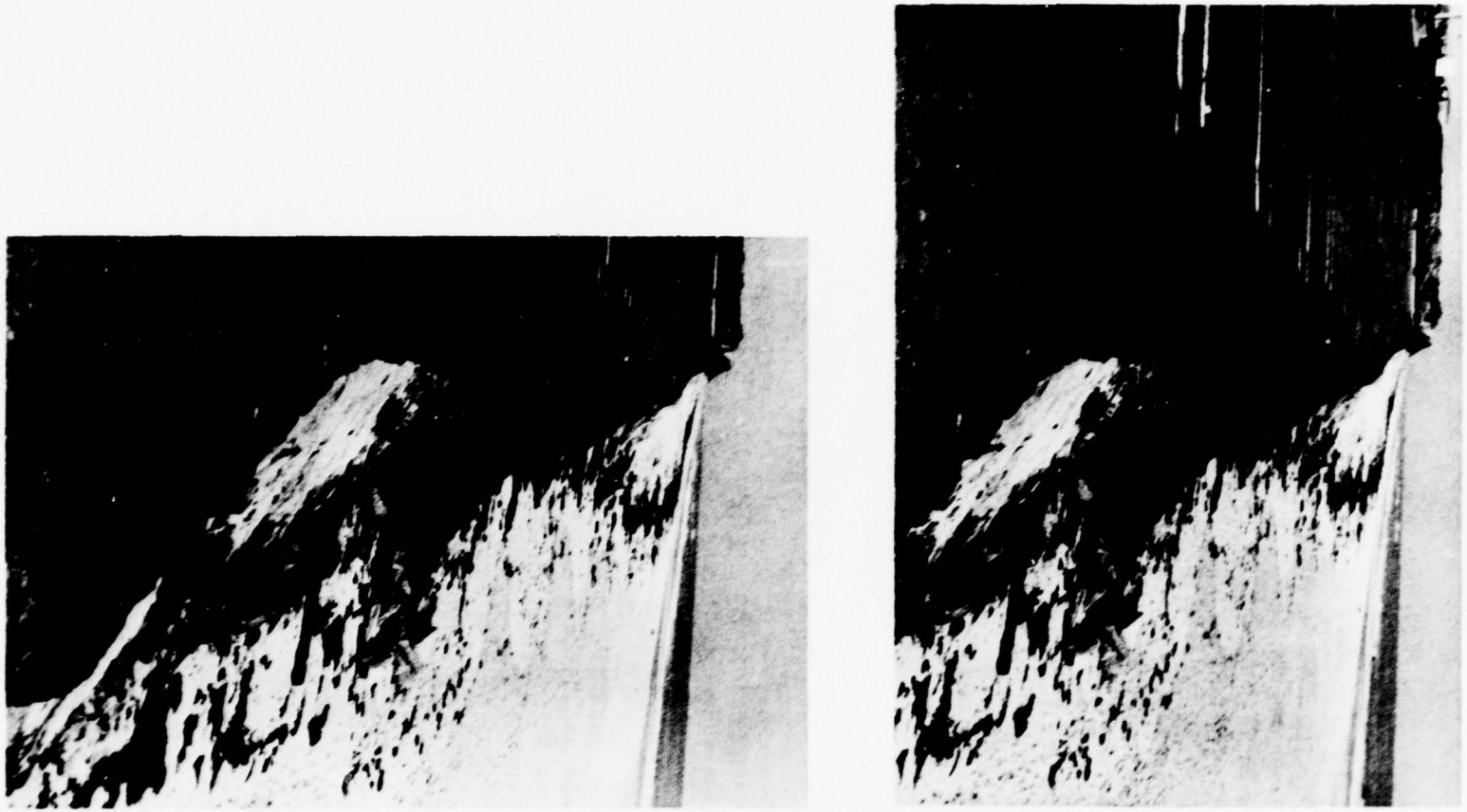

Figure 6. Erosion of the parking lot at Coast Guard Beach, Eastham, Massachusetts

When the climate of the area began to warm, the glacial ice melted, causing sea level to rise. When the sea rose to almost its present level, the Cape probably looked much different than it does today. Instead of a gently curving coastline, the shore probably had an irregular outline with bays and headlands. The Cape did not extend as far north, Provincetown and the northern end of Truro did not exist, and the outer Cape extended farther to the east than it does today. The shoreline may have been one or two miles east of the present shoreline, perhaps even more. Waves acted on the Cape to erode the headlands, and sand carried away from the headlands was deposited to form the Provincelands and, eventually, the barrier beaches. Winds formed the dunes that are such a familiar part of the Cape's landscape today. Storms, winds and waves have continued to erode the glacial material of the Cape and change its appearance. Beach and dune deposits and saltwater marshes now found on the Cape were deposited in post-glacial times.

b. Littoral Materials

(1) Characteristics. Geologic quadrangle maps for the outer Cape show that beach deposits on the Atlantic coast consist of sand to small boulders deposited by wave action and longshore currents. Near glacial deposits, the beach deposits may contain medium to very large boulders. Dune deposits in the Chatham and Orleans quadrangle (and in Provincetown) are wind-deposited sand to small pebbles derived from beach deposits. In the Wellfleet and North Truro quadrangles, windblown sand derived from beach deposits has formed hillocks and ridges parallel to the coastline. Irregularly shaped dunes and cliff-top dunes have also been formed in this area. The parabolic dunes of Provincetown and North Truro consist of sand and small pebbles in U- and V-shaped dunes that are concave toward the prevailing northwest winds.

Median grain size generally decreases from Provincetown to Chatham on the Cape's Atlantic coast. Along the Provincetown spit, median grain size is in the coarse to very coarse sand range. Median grain size for beaches fronting the marine cliffs is within the coarse to medium sand size, while on the southern beaches, median grain size is in the medium sand range (Fisher, 1972).

(2) Sources. The unconsolidated material that constitutes the glacial deposits on Cape Cod is the source of beach deposits on the Cape. Storm waves attacking the marine cliffs remove sand, pebbles and gravel, which are subsequently moved along the coast by longshore currents. Material is moved both north and south along the Cape's Atlantic coast. The location at which the longshore transport changes from north to south is unknown, but Wellfleet has been suggested as the possible area.

Dunes derive their materials from the adjacent beaches. This is particularly evident at Provincetown where sand deposited on the northern coast has been blown inland to form the Provincelands.

c. Erosional Forces

(1) Tides. The tides along Cape Cod's easterly shores are semidiurnal: two nearly equal low tides and two nearly equal high tides occur in about 24 hours and 50 minutes. Mean tidal range generally decreases from Provincetown to Chatham; the mean range at Provincetown is 9.1 feet while the mean range on Chatham's outer coast is 6.7 feet. At the inlet to Nauset Harbor, mean tidal range is 6.0 feet, decreasing to less than 3 feet in Nauset Bay. At Chatham, mean ranges also decrease from 6.7 feet on the Atlantic coast to 3.6 feet in Chatham Harbor and 3.2 feet in Pleasant Bay. Spring tides increase the range at Provincetown to 10.6 feet and the range at Chatham to 7.8 feet. Storms have increased the stillwater tide level at Provincetown to 9.8 feet above mean sea level during a northeaster on 26 December 1909 and to 8.3 feet above mean sea level during hurricane "Carol" on 31 August 1954. The 100-year frequency tide level for the eastern exposure from Provincetown to Chatham is estimated to be 10.0 feet above mean sea level.

(2) Waves. Wave observations over a 3-year period at a station off Nauset Beach (Eastham) indicate that the maximum waves occur from the east-northeast and east. Over 30 percent of the time, waves from the east-northeast were experienced. Waves from the east occurred more than 25 percent of the time. Waves approached from the east-southeast about 7 percent of the time, while waves from each of the other directions (NE, SE, SSE, S, SSW and SW) occurred less than 5 percent of the time. Waves from the southeast lose energy when they travel across Georges Bank and Nantucket Shoal; waves from the northwest, west and southwest affect Cape Cod's bay side shore.

(3) Winds. Northeast storms produce onshore winds on outer Cape Cod, raising the water elevation along the coast. A 10-year wind record for Logan Airport, Boston, shows that winds in excess of 32 miles per hour have a high frequency of occurrence in the northeast and northwest quadrants. Northeast winds are associated with storms; northwest winds have been responsible for the formation of the parabolic dunes in Provincetown and North Truro.

(4) Currents. Longshore currents are predominantly to the north along the Atlantic coast north of Wellfleet and south along the shore south of Wellfleet. These currents affect sand movement along the shore and influence the shape of the Cape.

(5) Storms. The easterly shores of Cape Cod from Provincetown to Chatham are particularly susceptible to storm surges caused by extra-tropical storms (northeasters). Extra-tropical storm surges of 2 feet or more occur at Boston about five times a year and surges of 3 feet or more usually occur annually. Northeasters can be particularly devastating when they occur in conjunction with a spring tide, and storms can reduce the height of a beach by as much as 10 feet. Hurricanes, although less frequent than northeasters in this area, have occurred. Due to its north-south orientation, the outer Cape coast is less susceptible to hurricanes than is the section of the Cape that faces Nantucket Sound (south). (For further information refer to the tidal hydrology section in Appendix 1 of Volume II.)

d. Wave Refraction

Waves frequently approach the Cape Cod coast at an angle rather than parallel to the coast. For example, waves from the northeast would strike the Orleans coast at an angle because the coast is oriented north-south. However, as the ocean wave moves shoreward, the bottom causes the wave front to curve so that the incoming wave is almost parallel to the shoreline when the wave breaks. This phenomenon is called wave refraction, because the wave front is refracted or bent. The breaking wave, however, is rarely perfectly parallel with the shore, and the angle that the wave front makes with the shore produces a longshore current. The longshore current transports sand along the shore.

Wave refraction can be modeled, and the model output is useful in determining the longshore currents and the amount of sediment moved by the currents. It is also helpful in determining where the direction of transport changes and where the shoreline process changes from erosion to accretion. The final result of the wave refraction analysis for Cape Cod is an estimate of the erosion and accretion rates for the easterly shores and a projection of where the shoreline will be located 50 years from now. (For details see Appendix 1 of Volume II.)

The analysis predicts that for average yearly conditions the net sediment transport will be to the north on the Atlantic coast north of Wellfleet and to the south on the Atlantic coast south of Wellfleet. The location where the transport changes from north to south is estimated to be near LeCount Hollow Beach, Wellfleet. Erosion is predicted along the shore from Head of the Meadow Beach, Truro, to Nauset Beach, Chatham. Accretion is predicted north of Head of the Meadow and on part of the northern coast of Provincetown. Erosion is predicted on the western coast of Provincetown. Agreement between predicted erosion rates and historical erosion rates is good for the scarp area. Rates along the barrier beaches and spits are difficult to predict accurately because of the intrinsic instability of these areas.

Based on the wave refraction analysis, erosion of 100 to greater than 150 feet is anticipated along the coast from Highland Light to Coast Guard Beach over the next 50 years. Accretion of up to 100 feet is predicted for parts of the northern Provincetown coast. Nauset Beach is expected to erode, but the predicted rates are subject to inaccuracies. More then 50 feet of erosion may occur on Provincetown's western shore.

e. Shore History

The easterly shores of Cape Cod consist of the beach and dune areas of Provincetown and North Truro, the marine scarp from North Truro to Eastham and the migrating spits and inlets of Eastham, Orleans and Chatham. The shore history in these areas will be discussed separately.

(1) The Great Hook of the Provincelands. The land north and west of High Head in North Truro, including all of Provincetown, has been formed since the retreat of the glacier. Longshore currents carried sand north, forming a hook and extending the northern coast of the hook seaward.

Herring Cove, which existed as a cove in 1848, gradually filled in as sand transported along the cove was deposited. From 1833 to at least 1952, the shoreline accreted at a slow rate; however, erosion has predominated during recent years.

Hatches Harbor, used by fishing vessels in the 1830's, has become a shoaled marsh. Sand, blown inland from Race Point, has been responsible for much of the shoaling.

Race Point and the northern shore of Provincetown have been growing seaward as material transported north along the coast is deposited. The shoreline at one location moved over 300 feet seaward between 1938 and 1974. Although accretion has predominated along this coast periods of erosion have occurred. Some of the material deposited on the beaches has been blown inland to form the dunes of the Provincelands.

To the east, along the coast near Head of the Meadow Beach, the shoreline process changes from accretion to erosion. Here the shoreline has alternately shifted landward and seaward. To the south, along the marine scarp, erosion has predominated.

(2) The Marine Scarp - Truro to Eastham. The coast of Cape Cod from High Head in North Truro to Coast Guard Beach in Eastham consists of a nearly continuous steep slope known as a marine scarp. Wave erosion of thick glacial outwash plain deposits has produced the scarp (Fisher, 1972). Where stream valleys have intersected the scarp, gaps are visible (Gatto, 1975). For much of its length the scarp is 50 to 150 feet high (Strahler, 1966). At a point 2 miles north of Newcomb Hollow Beach near the Truro-Wellfleet town line, the scarp reaches nearly 180 feet (Gatto, 1975).

The scarp, extending about 15 miles along the outer Cape shore, indicates that at one time the Cape extended farther to the east than at present (Fisher, 1972). Early investigators estimated the original extent as about 2-1/2 miles farther to the east (Davis, 1896, cited in Fisher, 1972) and as between one-half mile and 4 miles (Shaler, 1897, cited in Fisher, 1972). Wave erosion has changed the original irregular shoreline to its present gently curving configuration.

Due to the presence of structures and government installations on this section of coast, detailed historical records of shoreline changes are available at several locations including Highland Light, Ballston Beach, Marconi Station and Nauset Light. The scarp at Highland Light has receded about 125 feet in the last 100 years. At Nauset Light, the edge of the bank has retreated more than 200 feet during the last 90 years. The high-water line at Nauset Beach moved 75 feet landward between 1938 and 1974.

Recession of the scarp on eastern Cape Cod is caused by erosion of the glacial material on the face of the scarp. Two major factors contributing to the erosion are wave attack on the base of the scarp and erosion of the scarp face by rain and runoff. Rain causes deposition of small fans of clay and gravel at the foot of the scarp (Zeigler, 1960). This material

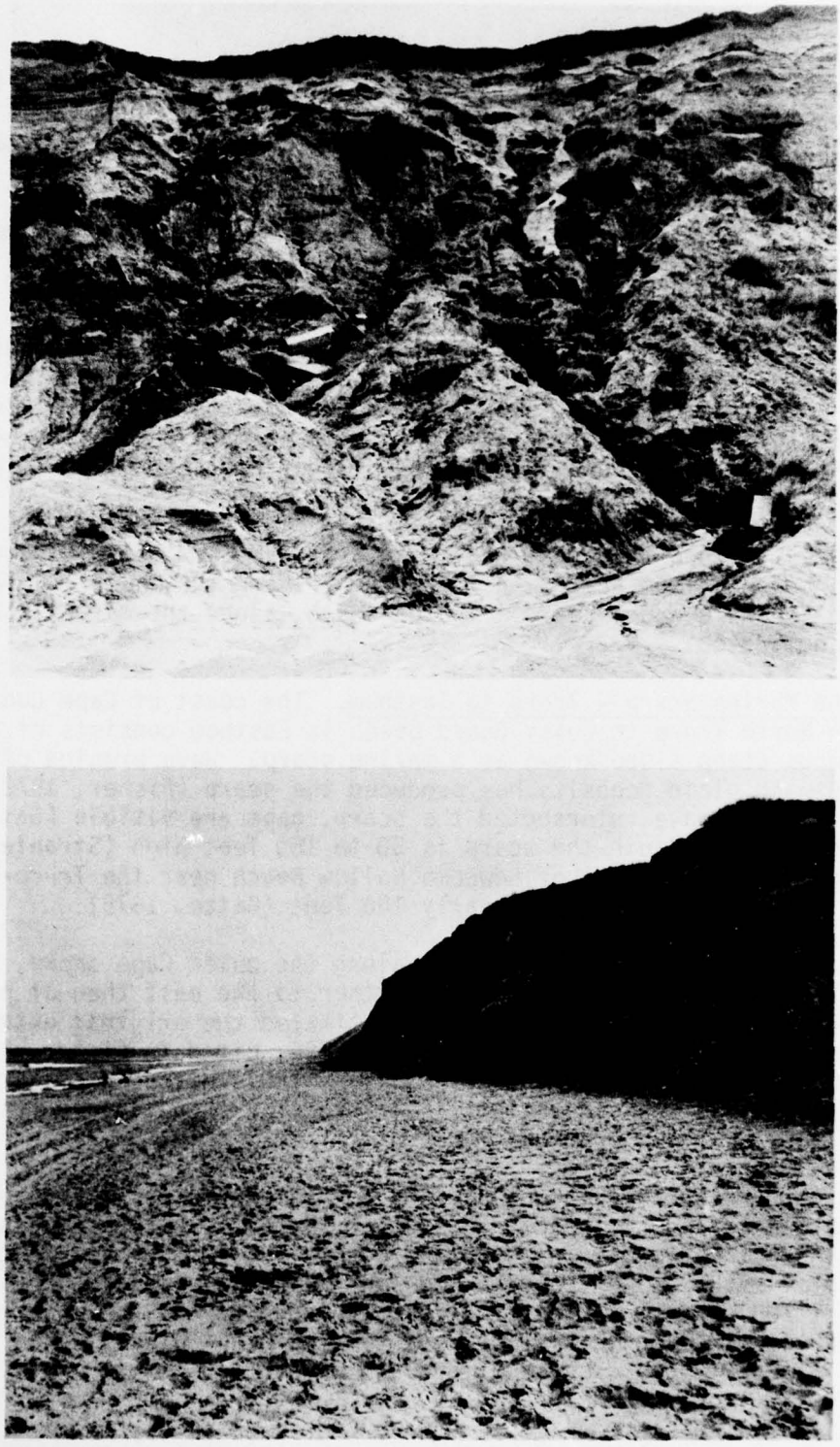

Figure 7. Erosion of the marine scarp, Atlantic coast of Cape Cod, Massachusetts

can then be carried out to sea by waves. Whether waves are able to reach the scarp or the material deposited at the scarp base depends on the condition of the beach. A wide beach protects the scarp base from waves; when the beach is wasted, waves attack the scarp directly (Zeigler et al, 1959).

Marindin of the U.S. Coast and Geodetic Survey conducted a careful survey of the Cape Cod coast from 1887 to 1889. By comparing his survey results with charts for 1848, 1856 and 1868, he determined the average erosion rate to be 3.2 feet per year for the section of coast from Highland Light to Nauset Light (Zeigler et al, 1964). His profile lines were reoccupied by Zeigler and his associates in 1958 and 1959. Their results showed that the main scarp was being eroded at an average rate of 2.6 feet per year (Zeigler et al, 1964). Erosion rates, however, are not uniform along the coast. In his analysis of aerial photographs, Gatto (1975) found that net rates of change from 1938 to 1974 varied from 0.1 to 7.3 feet per year, with the greatest net changes occurring near Highland Beach and north of Nauset Beach.

(3) Migrating Inlets and Spits. From the southern end of Coast Guard Beach, Eastham, to the tip of Nauset Beach, Chatham, Cape Cod's eastern coast consists of a series of barrier beaches, spits and inlets. Coast Guard Beach is located at the northern end of a spit that separates Nauset Harbor and Nauset Bay from the ocean. Nauset Harbor inlet separates this northern spit from the southern spit in the Nauset Harbor complex; the southern spit extends north from Nauset Heights, where a marine scarp is visible. South of Nauset Heights, Nauset Beach extends southward in the towns of Orleans and Chatham, finally terminating at the entrance to Chatham Harbor and Pleasant Bay. South of Chatham Harbor, Monomoy Island reaches out into Nantucket Sound.

Material eroded from the marine scarp to the north and carried south by longshore currents has built Nauset Beach and Monomoy Island. Continued erosion, transport, and wave and tidal action cause the spits to increase and decrease in length, to migrate into the marshes behind them, and to change shape. Dramatic growth and retreat in short periods of time have been recorded. Migration of the shoreline westward has generally occurred at a slower rate; the barrier beaches are retreating and the scarps are eroding at approximately the same rate (Zeigler et al, 1964).

Westward migration of the barrier beach has been evident at the Old Harbor Life Saving Station site. At the time of construction of the station, the spit was approximately 1100 feet wide at the southernmost extension of the spit. The station was constructed about 500 feet north of the tip and approximately in the center of the spit. In 1910, a Coast Guard survey showed that the station was 600 feet from the mean high-water line on the Atlantic Ocean side. In 1940, approximately 1000 feet of dry beach existed on the Atlantic Ocean side of the station, with 10- to 12-foot high dunes. By 1966, only 100 feet remained between the building and the high-water line and by 1977 waves were breaking against the foundation of the Old Harbor Station.

Figure 8. Erosion of the marine scarp, Atlantic coast of Cape Cod, Massachusetts

The shoreline at Nauset Harbor is constantly changing as the inlet to the harbor migrates north and south and the barrier beach migrates landward. Prior to 1938, the inlet was located at Nauset Heights, and no southern spit existed; as the southern spit formed and grew, the inlet migrated northward. In September 1977, the southern spit was more than a mile in length.

Like Nauset Harbor's inlet, the inlet to Chatham Harbor has changed, and the changes have occurred in cycles. The most recent inlet migration cycle identified by Goldsmith (1972) began in 1846 when the inlet was in the same location as it was in 1971. A breakthrough was formed in 1846 and a new entrance to Pleasant Bay was formed. The spit on which Old Harbor Life Saving Station was built grew southward, extending approximately 6 miles south of its 1846 location (Goldsmith, 1972). (For a further discussion of shoreline changes, refer to Appendix 1 of Volume II.)

Erosion Problems

Erosion becomes a problem on Cape Cod when it threatens any of the Cape's assets, whether natural or man-made. Structures, ground water supplies, shellfish beds and harbors located in critical erosion areas have all been endangered by increasing erosion. Areas of erosion and potential erosion problems predominated at most locations along the coast from Long Point to Race Point (Provincetown) and from Head of the Meadow Beach (Truro) to the southern portion of Monomoy Island.

Erosion at a rate of approximately 3 feet per year along the marine scarp threatens property and structures including private residences and navigational aids. Where the beaches are backed by dunes instead of the marine scarp, erosion of the dunes may cause damage to upland features. For example, at Ballston Beach a dune separates the Pamet River Valley from the Atlantic Ocean. If the dune were permanently breached, saltwater encroachment on the ground water of the area could result.

On the barrier beaches, wave action particularly during storms may cause the beaches to be overtopped, and a new inlet through the barrier beach could be formed. This process has occurred in the Old Harbor area of Nauset Beach and could occur along the north and south spits at the inlet to Nauset Harbor. The barrier beaches themselves are migrating landward and encroaching on the marshes. Sand washed over the beach or blown toward land has covered shellfish beds and shoaled navigation channels.

Inlets to Chatham and Nauset harbors shift, and some of the sand moving along the coast is deposited in the harbors. Navigation channels are difficult to maintain, and the usefulness of the harbor as a port of refuge during storms is diminished.

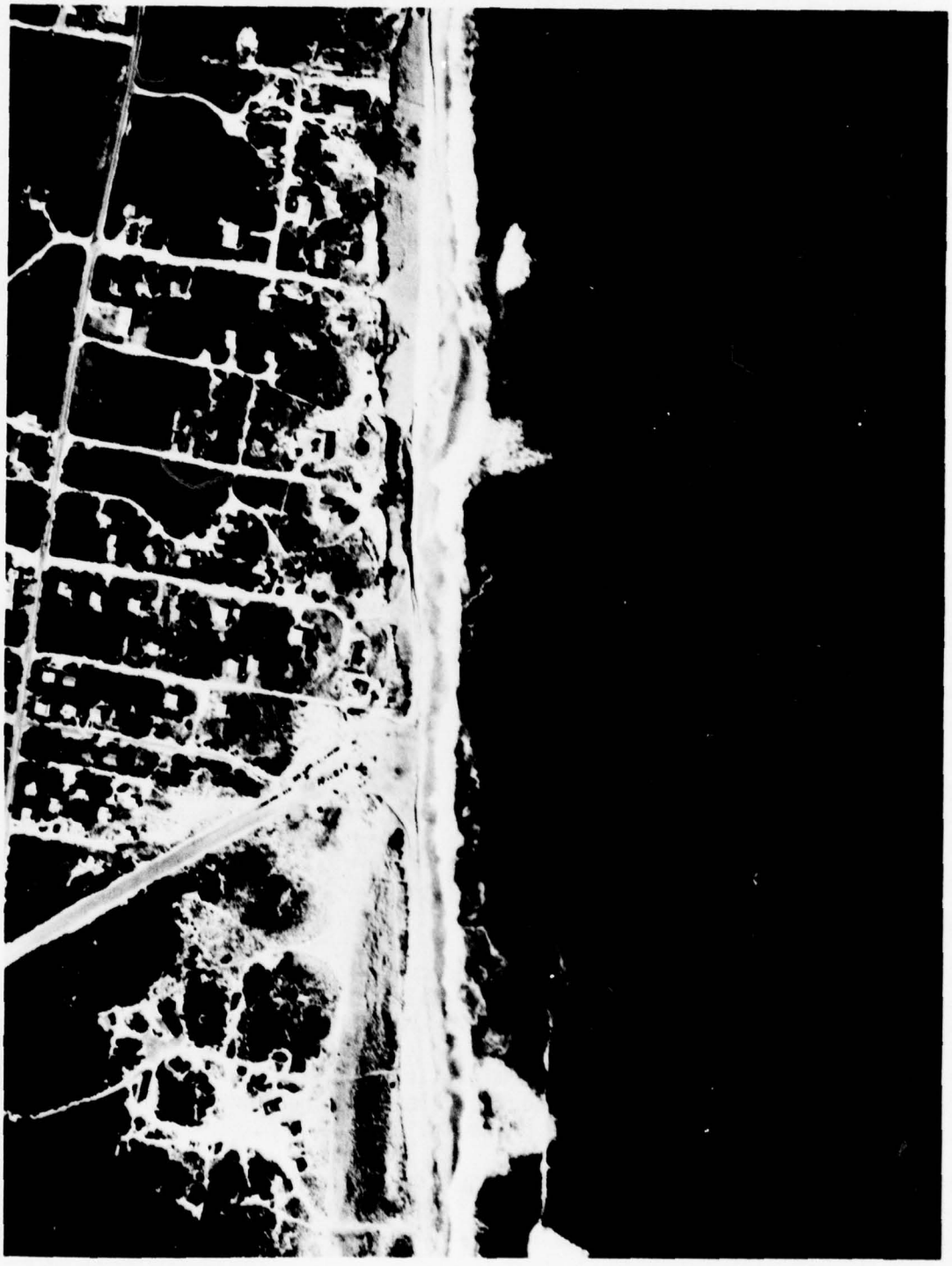

Figure 9. Development near top of scarp, Wellfleet, Massachusetts

Figure 10. Dunes separating Pamet River Valley (left) and Atlantic (right), Cape Cod, Massachusetts

Erosion problems are aggravated by abuse of vegetation that holds the sand in place. Pedestrians and beach buggy drivers who stray from established trails accelerate the erosion.

Recreational Needs

Cape Cod provides unique opportunities for swimming, boating, fishing, shellfishing, bicycling, hiking and sightseeing and attracts large numbers of visitors to the Cape. Visits to the National Seashore exceeded 5 million in 1976. Tourists, summer visitors and residents use the Cape's recreational resources and the income generated by tourism is an important part of the Cape's economy.

Recreational demand for beach activities (swimming, sunbathing) on the Cape is presently being satisfied and additional opportunities exist; underutilization of the beaches, however, is due in large part to lack of adequate parking and beach facilities and inaccessibility of some beaches. Demand for some recreational activities such as boating far exceeds the supply, because boating is restricted by the available launching sites, slips, moorings and anchorage areas. The size of boats that can navigate through the inlets is limited by the depth of the navigation channels which constantly shoal and shift. Camping sites are also limited, but satisfying this need may be difficult because some towns have restricted the development of additional campsites.

Off-the-road vehicles (ORVs) are very popular on the Cape, and jeep trails are established in the Cape Cod National Seashore. ORVs provide access to remote parts of the beach for beach goers and fishermen.

Wise management of the Cape's resources will be necessary to provide recreational opportunities while avoiding conflicting uses, overutilization and misuse.

Status of Existing Plans and improvements

Structural improvements have been proposed for both Chatham and Nauset harbors. Neither plan was implemented. The plan for Chatham Harbor would have provided sufficient benefits to justify federal participation and cost sharing, but the local contribution required was prohibitive. Improvements proposed for Nauset Harbor could not be justified on the basis of the benefit-to-cost ratio. (Improvements have been made at Stage Harbor, Chatham, but Stage Harbor is not included in the study area for the present report.)

Figure 11. Off-the-road vehicles on Race Point Beach, Provincetown, Massachusetts

At Herring Cove Beach, Provincetown, an asphalt seawall has been constructed. This structure is presently crumbling at its southern end. Four groins located at Herring Cove Beach are in disrepair and provide little protection from erosion.

Structural solutions were also implemented at Coast Guard Beach, Eastham. Between 1966 and 1972, rubble was placed in front of the parking lot and bathhouse in an attempt to slow the erosion. The rubble appeared to accelerate erosion in adjacent areas and it became a hazard to swimmers, necessitating its removal. In February 1978, the beach was leveled by a northeaster and the bathhouse and parking lot were damaged. The bathhouse was subsequently removed.

Improvements Desired

Extensive improvements have been considered for Nauset and Chatham harbors, and both areas have been studied in detail by the Corps of Engineers. Neither of these plans has been implemented because of environmental and cost considerations. Due to the economic and recreational importance of these areas, local interests are becoming more concerned with the seriousness of the problem. As a result, extensive improvements are still desired. Another area of particular concern is the Pamet River, and measures are desired that will prevent the ocean from encroaching on the river valley and ground water located immediately behind the dunes.

Property owners are concerned with loss of land and have expressed a desire to see structural or non-structural improvements implemented. However, consciousness of possible adverse effects is high among Cape Cod residents and improvements are desired that do not benefit one area at the expense of another. The need for preservation rather than exploitation has also been expressed.

In general, the local populace desires improvements that will maintain Cape Cod in its present state, provide adequate recreational opportunities by careful management of existing resources, and insure the preservation of the unique characteristics and quality of life that attract people to the Cape.

Figure 12. Asphalt seawall and groins at Herring Cove Beach, Provincetown, Massachusetts

PLAN FORMULATION

Erosion of Cape Cod's easterly shores by wave, wind, storm and man has resulted in loss of property including houses, roads and parking areas. This has prompted the movement of other houses and navigation aids. Projections indicate that the erosion will continue, threatening additional land and structures. These conditions emphasize the need to consider possible methods for protecting the shoreline. Additional considerations include the provision of recreational beach space and the minimization of possible adverse environmental impacts. Several alternative plans of improvement and their ability to fulfill these criteria were investigated. A complete description of the considered structural plans is contained in Appendix 2 of Volume II.

FORMULATION AND EVALUATION CRITERIA

Alternative plans appropriate for beach protection or erosion control were formulated and evaluated to detemine whether they met applicable criteria. Technical, economic and environmental aspects of any proposed plan must be considered. The criteria used to evaluate the plans are enumerated below.

a. Technical Criteria

(1) Protection should be provided against the storm tide level that would be generated by a severe northeaster calculated by using a critical combination of meteorological and hydrological conditions reasonably characteristic of the area.

(2) Protective works should be designed to minimize the amount of overtopping expected to occur during the design storm.

(3) Wave heights used should be those expected to occur in conjunction with the design storm producing the design tidal flood level.

(4) For alternative plans which call for the placement of artificial sandfill to form a protective barrier beach, the beach berm should be designed with sufficient height and width to dissipate the wave energy produced by the design storm and to resist erosion to the extent that the protective works will not fail during the design storm.

(5) A freeboard allowance of at least one foot of height should be assumed for revetment structures and at least two feet for sand dunes.

b. Economic Criteria

(1) Tangible benefits exceed project costs.

(2) Each separate unit of improvement provides benefits at least equal to its cost.

(3) The scope of the plan provides for the maximization of net benefits.

(4) There is no economical means, evaluated on a comparable basis, of accomplishing the considered improvements.

In addition, the benefits and costs have been expressed in comparable quantitative economic terms, whenever possible. The costs which were developed for the alternative plans were based on a 50-year amortization period and an interest rate of 6-7/8 percent. The annual costs also include the cost of maintenance and sand replacement.

c. Environmental and Other Criteria

(1) Public health, safety and social well-being.

(2) Provisions for visually pleasing esthetics and other desirable effects or features.

(3) Avoidance of detrimental environmental effects to the maximum extent possible.

POSSIBLE SOLUTIONS

Both structural and non-structural plans of improvement should be considered when determining the most appropriate erosion control measures to implement. Alternatives include:

a. Structural Measures

Rock Revetment
Nearshore Stone Mound
Offshore Stone Breakwater
Precast Concrete Section/Concrete Leveling Slab/Rubble Mound
Stone Groins
Stone Groins and Placed Sandfill
Placed Sandfill Only

b. Non-structural Measures

Zoning Regulations
Building Codes
Sand Dune Use Regulations
Storm Warning System
Emergency Evacuation Plan
Dune Grass Planting

Land Acquisition for Open Space Needs and Buffer Zones
Flood Proofing Structures
Sand Fences
Public Education and Awareness Program

The structural measures are discussed in more detail in the following section. The non-structural measures are touched on briefly in the same section, but a more detailed discussion can be found in the section on plans for non-federal interests to consider (this volume) or in the survey reports for the individual towns and beaches in Volume III.

CONSIDERED PLANS

Several protective measures, both structural and non-structural, are commonly employed in attempts to protect beaches and prevent shoreline erosion. Seven alternative structural methods are evaluated in Volume II of this report. Non-structural methods are discussed later in this volume and specific suggestions are made in Volume III. The costs associated with the structural plans are presented in Appendix 2 of Volume II and estimates of the benefits are given in Appendix 3 of that volume.

The geographic limits of the proposed plans are more restricted than the geographic limits of the study area. Structural plans considered involve 100,000 feet of shoreline on the Atlantic coast of Cape Cod from near the Provincetown-Truro town line to Coast Guard Beach. This is the approximate region of the rapidly eroding marine scarp, but it is not the only area where erosion is occurring. The barrier beaches south of Coast Guard Beach are retreating landward at approximately the same rate at which the scarp is eroding. The western shore of Provincetown and the Wood End to Long Point spit are also experiencing erosion. However, attempting to control erosion on the barrier beaches has proved ineffective in areas such as Cape Hatteras National Seashore and may actually have aggravated the problem. It is also possible that implementing erosion control measures along the scarp may accentuate the erosion in other areas such as the barrier beaches by reducing their supply of littoral materials. This potential impact will have to be considered in any plan found economically justifiable. (Refer to Appendix 2 of Volume II for diagrams of the plans discussed below.)

Plan I consists of a rock revetment located along the base of the dunes and extending 100,000 feet parallel to the shore. The revetment would be constructed on a gravel base covered by underlayer stone and armor stone. Like Plans II and III, the revetment would be designed as protection from wave attack. Usable beach and access to the water would be lost; downdrift beaches would be starved.

Plan II consists of a nearshore stone mound located about 50 feet seaward of the back edge of the berm and extending 100,000 feet parallel to the beach. The mound would consist of core stone covered on the top and seaward side by armor stone. Sandfill would be placed behind the mound. Usable beach area would be increased, but the only access to the water from the beach would be across the stone mound. Waves approaching the beach would break on the seaward side of the mound instead of on the beach, thus protecting the beach and upland areas. Erosion in adjacent areas and at the foot of the structure on the seaward side may be accelerated by the presence of the structure.

Plan III involves constructing a stone breakwater approximately 1200 feet offshore and extending 100,000 feet parallel to the shore. The breakwater would consist of a stone core enclosed in armor stone. Because the wave forces acting on the beach are diminished by the breakwater, this structure should lessen the erosion and longshore transport. The presence of the breakwater may reduce the amount of sand supplied by littoral transport to the downdrift beaches. This is the most costly of the seven structural solutions considered.

In Plan IV, a typical precast concrete section placed on a concrete leveling slab atop a rubble mound is considered. The structure would be located on the shore and would extend 100,000 feet parallel to the shore. Like Plan II, the structure would be designed to provide protection from wave attack. However, it also might aggravate erosion on adjacent beaches and accentuate erosion at the toe of the structure, causing loss of beach.

Plan V consists of a system of 101 groins constructed of armor stone, spaced 1,000 feet apart along the 100,000-foot improvement plan area and extending 245 feet seaward. Groins are useful in reducing the longshore transport out of an area. They can provide storm protection if they are successful in creating a wide beach that can dissipate storm waves before the waves reach the scarp.

Plan VI is a combination of Plan V (Stone Groins) and Plan VII (Placed Sandfill). Groins would be spaced 1,000 feet apart along the beach and would extend 315 feet seaward from the backshore. The landward end of the groin would be covered by sandfill to a minimum depth of 1 foot. Like Plan V, the groins and sandfill would interrupt the longshore transport; storm protection would be provided when the beaches were full.

Placement of sandfill along 100,000 feet of shore front is considered in Plan VII. A berm 100 feet wide would be provided in this plan. Usable beach space would be increased and the beach's ability to dissipate storm energy would be enhanced. Beach nourishment may benefit rather than harm adjacent areas; however, maintaining the beach, particularly in a high-energy wave environment like Cape Cod, may require continual replenishment.

Non-structural measures can also be used either in conjunction with the structural plans or separately to reduce at least man's contribution to erosion.

Plan VIII includes dune restoration and beach grass planting along approximately 70,000 feet in conjunction with restriction of sand dune use, controlled access to beaches, sand fencing, public education and awareness programs and controlling off-the-road vehicle impact. These efforts can be employed to reduce erosion caused by man. They also can be used in an effort to slow the natural erosion process, but they must be viewed as only temporary measures. Many non-structural controls have already been implemented by the National Park Service. Perhaps the most important is the regulation of construction which will limit development of the area most threatened by erosion. This plan extends from Coast Guard Beach south to the southern tip of Nauset Beach but can also apply to other areas. This plan could be considered between Long Point and Race Point in Provincetown as well.

First costs for structural and non-structural plans of improvement are presented in Table 1.

ENVIRONMENTAL CONSIDERATONS

Proposed improvement plans discussed in the previous section could have both good and bad effects on the environment if implemented. Likewise, taking no action and allowing nature to take its course will have good and bad impacts on the Cape. Some possible effects of each course of action are described below.

a. Without Improvements

Natural physical processes, if unimpeded, will continue to cause the marine scarp to erode. The major impact will be the loss of property and the possible loss of structures or the need to relocate them. Future development along this coast is regulated by the National Park Service so the shore will be protected from extensive development that requires protection along other eroding shores. Refer to Volume II for a map showing the shoreline retreat anticipated during the next 50 years.

Accretion will continue along the northern shore of Provincetown and windblown sand will continue to be a problem. The impact of off-the-road vehicles has been felt in this area and abuse will probably increase if awareness and educational programs are not implemented.

Herring Cove Beach and other parts of the western shore of Provincetown have been eroding and this trend is expected to continue, while Nauset Beach from Coast Guard Beach to Chatham Harbor inlet will continue to migrate landward and sand will encroach on the marshes and bays behind the barrier beach. This

Figure 13. Sand fence experiment near Old Harbor Life Saving Station site, Chatham, Massachusetts

Table 1. Improvement Costs

Plan No.	Description	Total First Cost (millions)
I	Rock Revetment	$ 35.97
II	Nearshore Stone Mound	147.00
III	Offshore Stone Breakwater	503.00
IV	Precast Concrete Section/Concrete Leveling Slab/Rubble Mound	66.18
V	Stone Groins	26.50
VI	Stone Groins and Placed Sandfill	86.60
VII	Placed Sandfill Only	60.14
VIII	Dune Restoration	5.33

will seriously impact the marshlands and shellfish beds. Biological communities in these areas may be seriously impacted (as in the case of sand covering shellfish beds) or displaced. In addition, natural processes may cause new inlets to form. The formation of a new inlet may change the salinity, temperature and tidal circulation in the harbors and bays behind the barrier beach. This impact could be harmful to species having low tolerance to change or it could be beneficial in areas where stagnation due to lack of circulation and tidal flushing has become a problem.

b. With Improvements

The impacts of proposed plans will depend largely on the plan of improvement selected. Slowing the erosion and protecting areas behind the beaches are the major beneficial impacts that could result from implementation of a structural plan of improvement. Possible adverse impacts include damage to downdrift beaches and alteration of the beach as it presently exists.

Beaches to the north and south of the 20-mile improvement area are supplied by material eroded from the scarp and carried north or south. If the scarp area were protected by a structural improvement, the supply of material would be diminished or eliminated. Without constant nourishment, the northern beaches at Provincetown would cease growing seaward and erosion along Nauset Beach would be accelerated. The impact that improvements can have on adjacent areas was demonstrated by the installation of rubble at Coast Guard Beach which caused increased erosion in adjacent areas.

Some of the proposed plans of improvements would drastically alter the beach as it exists today. Obviously, there would be a significant visual impact associated with any of the structural plans. The offshore breakwater would be an imposing sight. The nearshore stone mound would form a barrier between the water and the beach. In addition, those plans designed to protect the scarp directly (such as the rock revetment) could result in the loss of the existing beach.

> ...if ever the cliffed section were completely paved by some method to prevent or slow down coastal retreat cutting off approximately one-half of the sand supply the beaches would disappear completely in 86 years and probably a lot sooner...(Zeigler et al, 1964).

In addition to the long-term impacts, adverse short-term impacts may be anticipated during construction. Non-structural alternatives should have less impact (either beneficial or detrimental) on the area. While non-structural solutions have fewer damaging impacts, they are not effective in controlling erosion over long periods of time.

ECONOMIC ANALYSIS

This section of the report addresses economic considerations associated with the considered plans of improvement that are presented in this report. Costs, benefits and economic justification for each of the structural plans are discussed. Appendix 2 of Volume II contains a more detailed discussion of the plans and an analysis of the first costs and annual charges for the individual plans. Economic factors are addressed in Appendix 3 of Volume II. All cost estimates are based on prevailing 1978 price levels. No economic analysis is presented for improvements suggested in Volume III for individual beaches and towns because of the difficulty in quantifying the possible benefits.

METHODOLOGY

In order to determine the economic justification for the considered structural plans of improvement, the equivalent average annual charges (i.e., interest, amortization and maintenance costs) must be compared with an estimate of the equivalent average annual benefits that would be realized over the assumed 50-year project life. Appropriate values of cost and benefits at their time of accrual are made comparable by conversion to an equivalent time basis using an appropriate interest rate. A directed rate of 6-7/8 percent applicable to public projects was used in this report.

FIRST COST

Estimated first costs for the considered structural plans of improvement are summarized in Table 1. These estimates include the cost of materials, contingencies, engineering and design work and supervision and administration charges.

ANNUAL CHARGES

Annual charges are based on the current interest rate of 6-7/8 percent with amortization over a 50-year period. The annual charges shown in Table 2 include an estimate for maintenance.

BENEFITS

An estimate of all the benefits expected to result from each of the alternative structural plans of improvement was made. The primary benefits are based on the dollar value of physical losses prevented and the increased supply of recreational space supplied by the project. Analysis shows that excess recreational beach space exists in the project area; therefore, benefits cannot accrue to any plan based on increased recreational beach space. Furthermore, several plans might result in loss of beach, producing a negative benefit. Thus, plan benefits are determined on the basis of physical damages prevented. Dollar values of projected physical losses prevented on an average annual basis over the 50-year life of the project are presented in Table 3.

Table 2. Annual Charges

Plan No.	Description	Annual Charges
I	Rock Revetment	2,966,000
II	Nearshore Stone Mound	12,082,000
III	Offshore Stone Breakwater	36,428,000
IV	Precast Concrete Section/Concrete Leveling Slab/Rubble Mound	5,360,000
V	Stone Groins	2,170,000
VI	Stone Groins and Placed Sandfill	6,708,000
VII	Placed Sandfill Only	4,792,000
VIII	Dune Restoration	981,000

Note: See Volume II for details.

JUSTIFICATION

Average annual benefits and average manual costs are compared and the resulting benefit-to-cost ratio is presented in Table 4. Only values that could be quantified are included. None of the ratios of benefits to costs for the considered structural plans of improvement economically justify federal participation or cost sharing in construction of a beach erosion control project along Cape Cod's easterly shores.

Table 3. Summary of Benefits

Category	Annual Benefit
Loss of Land	$679,000
Loss of Parking Lots and Roads	17,600
Residences	72,000
Bathhouses	6,000
Other (lighthouses, radio towers)	10,000
TOTAL	$784,600

Table 4. Summary Economic Analysis

Plan No.	Description	Annual Benefits	Annual Charges	Benefit to Cost Ratio
I	Rock Revetment	784,600	2,966,000	.26
II	Nearshore Stone Mound	784,600	12,082,000	.06
III	Offshore Stone Breakwater	784,600	36,428,000	.02
IV	Precast Concrete Section/Concrete Leveling Slab/ Rubble Mound	784,600	5,360,000	.15
V	Stone Groins	784,600	2,170,000	.36
VI	Stone Groins and Placed Sandfill	784,600	6,708,000	.12
VII	Placed Sandfill Only	784,600	4,792,000	.16
VIII	Dune Restoration	--	981,000	--

SELECTED PLAN

During this study, available literature concerning erosion on Cape Cod's easterly shores was reviewed and views of local citizens and interested agencies were sought and incorporated. Seven structural plans of improvement and their associated costs, benefits and impacts were considered.

None of the considered plans could be justified on an economic basis. All benefit-to-cost ratios were less than 1.0, which is the minimum acceptable ratio for federal participation and cost sharing. Benefits resulting from the improvements might be produced at the expense of adjacent areas. Loss of recreational beach space would result from some of the plans, and most of the plans would have a significant visual impact. Also, lessons learned in other areas indicate the enormous expense involved in return for uncertain result when trying "to hold the line" against erosion.

Due to the lack of an economic justification and to the possible adverse impacts, federal participation in any of the considered structural plans cannot be recommended. Therefore, consideration should be given to non-structural erosion control methods. These methods could be implemented at the local level and include grass planting, controlled access, vehicle control and educational programs, etc. Federal and state agencies with expertise in these areas could assist in developing programs that will aid the towns in their efforts to educate the public on the importance of preserving the beaches.

PLANS FOR NON-FEDERAL INTERESTS TO CONSIDER

Plans for individual beaches and towns are contained in Volume III of this report, but general guidelines are summarized here. An excellent reference for recommendations (some of which are included here) is Dr. Paul Godfrey's article, "Management Guidelines for Parks on Barrier Beaches."

One of the most important factors in erosion control is minimizing abuse and overutilization in fragile erosional areas. These areas include dunes, marshes, scarp faces, washovers, blowouts, vegetated areas and barrier beaches. A number of measures can be employed to reduce man's impact:

Control pedestrian access to the beach.

- Provide boardwalks on heavily travelled paths.
- Provide stairs where beachgoers presently walk down the scarp face or across dunes.
- Fence off vegetated areas that might be used as a shortcut between parking lots and the beach.

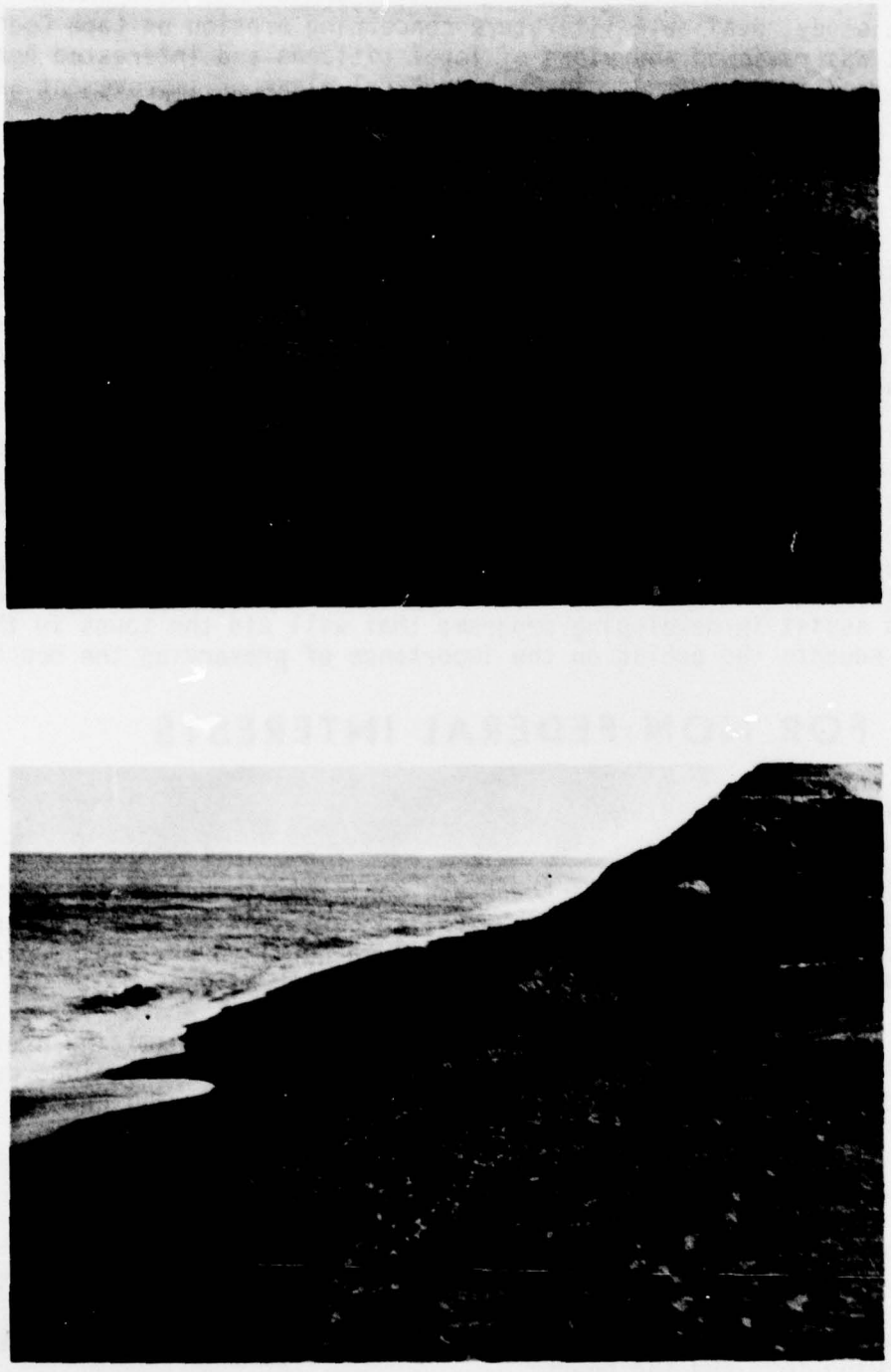

Figure 14. Evidence of foot traffic on the dunes and scarp face, Cape Cod, Massachusetts

- o Design beach access paths that minimize the effects of wind and wave erosion.
- o Mark trails clearly and border the trails with fencing or shrubs to protect vegetation.
- o Provide access stairs and platforms on dunes the people are likely to climb; prohibit climbing on other dunes.
- o Develop public awareness and information programs to stress the need for conservation and erosion control.
- o Develop a program of sand fences to trap windblown sand and develop or improve dunes.

Control the impact of off-the-road vehicles (ORVs).

The following suggestions have been developed by Dr. Godfrey in his studies of ORV impact:

The best management approach to solving vehicle problems is not to open areas that have been closed or have previously been inaccessible. Provide controlled, public transportation to inaccessible areas, if really necessary, or encourage visitors to walk.

Where vehicles must be allowed for any compelling reason, certain management procedures can be followed:

- o Prevent indiscriminate traffic on dunes.
- o Restrict traffic to marked routes along which borders of cable or dense shrubs are established after careful study.
- o Vehicle tracks must be controlled and maintained. Deterioration of the track (such as development of washboard ruts) often will spur drivers to go off the established path and create new ones.
- o Restrict traffic to intertidal ocean beaches where surveys show relatively few marine animal populations are present. Where possible, a marked route should be established on the berm to prevent indiscriminate driving over the beach.
- o Route traffic on the beach around sites of significant dune formation, particularly where driftlines and seeds accumulate.
- o Prevent all traffic across salt marshes and intertidal flats, or along the borders between marshes and sand dunes.
- o Close off overwash passes between dunes and prevent vehicle use of these openings. Such passes eventually close and develop new dune systems. Vehicle traffic will prevent the natural processes from closing the gaps.
- o Ramps should be built over dunes where access to the beach is desired. Once built, such ramps will require periodic maintenance, especially following storms.
- o Close off bird and marine turtle nesting sites and important feeding areas. Appropriate signs which explain the need for protection should be erected at some distance from the actual nesting sites. People on foot, leaving a vehicle to read a small sign near a nesting area, can cause more disturbance than a vehicle passing in front of the colony.

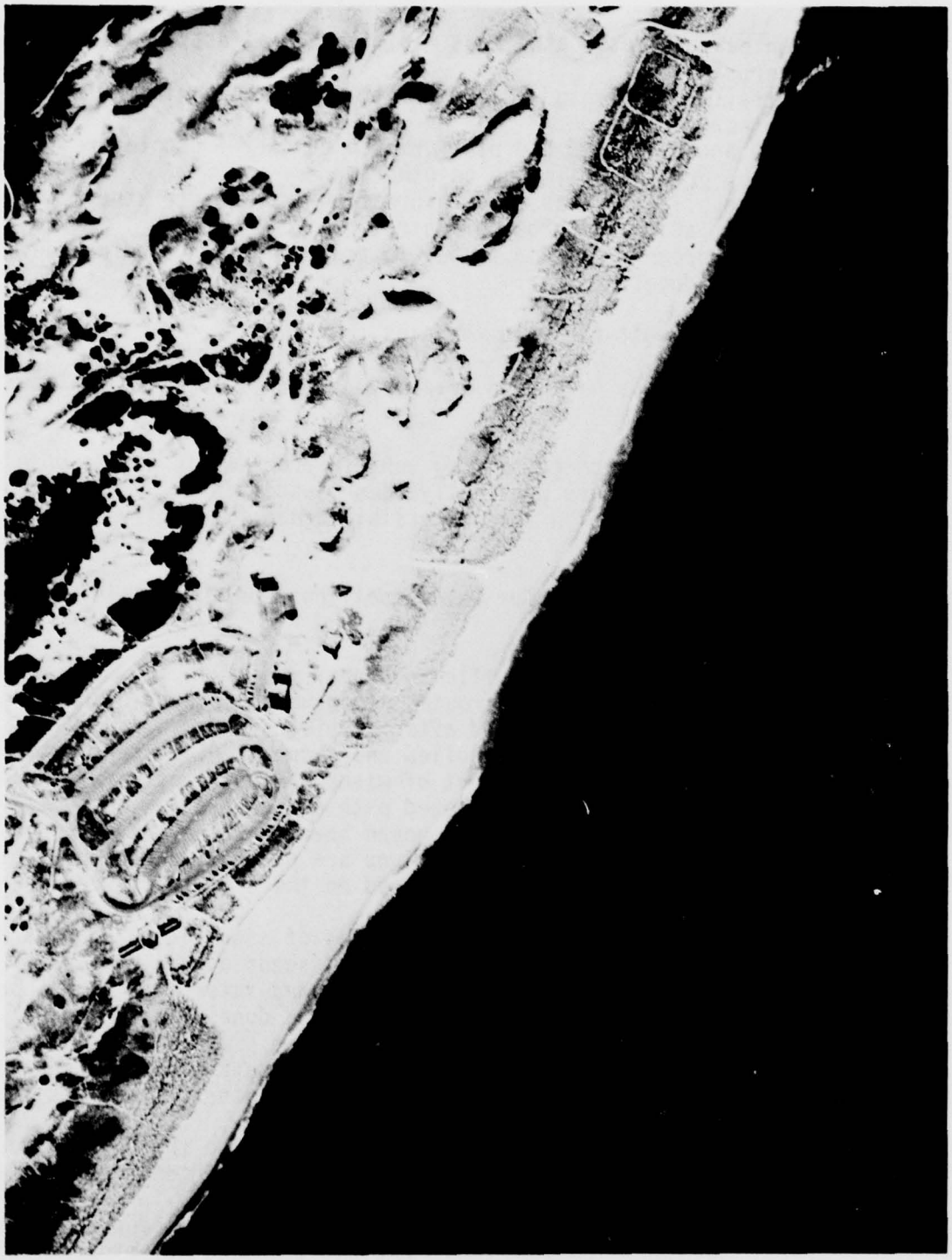

Figure 15. Experiment near Race Point Beach, Provincetown, Massachusetts, showing the effects of off-the-road vehicle traffic on vegetation

- o Close beaches to vehicles during periods of exceptionally high tides which would force drivers to run up the faces of dunes, often through nesting sites and incipient dune areas. (Godfrey, 1978)

Protect threatened areas from development. This can be accomplished in several ways:

- o Establishment of zoning regulations and building codes
- o Land acquisition for open space
- o Siting parking facilities away from and providing access to the beaches.

Allow natural processes to provide protection wherever feasible.

- o Where dunes are the only protection against wave attack on uplands, allow them to migrate naturally. Do not build structures or roads that will interfere with the dune's natural recession.
- o Stabilize dunes with beach grass in areas such as the Provincelands, where the natural process favors dune stabilization.
- o Plan beach facilities so that they do not interfere with natural processes. Consider providing access from inland locations.

Maintain education and public awareness programs.

- o Pedestrians and ORV drivers should be alerted to the impact they can cause when they leave established trails.

Additional recommendations include:

- o Control drainage from parking areas so that it does not overfall over the scarp faces.
- o No plan of improvement that would threaten the integrity of the barrier beach should be implemented.
- o Building codes should reflect the latest criteria and standards for coastal areas.
- o Develop a storm warning system and evacuation plan in case of emergency.

COORDINATION WITH OTHER AGENCIES AND LOCAL INTERESTS

To obtain the views of the local citizenry, the project area towns and interested agencies, a public meeting was held on 28 November 1973 in Eastham, Massachusetts. The National Park Service was represented by then Superintendent of the Cape Cod National Seashore, Mr. Leslie Arnberger. The individual towns were represented by their selectmen and interested citizens. Representatives of the Cape Cod Bird Club, the Chatham Jaycees and the Pamet Harbor Committee presented the views of their respective organizations. Members of the scientific community also contributed to the meeting. A letter

was submitted by the Fish and Wildlife Service of the U.S. Department of the Interior expressing interest in the proposed study.

Subsequent to the general public meeting, members of the U.S. Army Corps of Engineers met with officials of federal and state agencies and project area towns, the Massachusetts Coastal Zone Management Program and the National Park Service on many occasions to discuss the progress of the study and the conclusions and recommendations.

Agencies and individuals contributing to the study and reviewing the final report are listed in the acknowledgements section of Volume II.
The study has received the support of the National Park Service and the project area towns since the beginning. Meetings have been held with officials of the Park Service, the individual towns and we have tried to comply with the Coastal Zone Management Program. (See Volume II Appendix 4 for additional details.)

REVIEW BY OTHER AGENCIES, ORGANIZATIONS, AND INDIVIDUALS

The comments and suggestions of others generated during the review cycle of this report have generally been incorporated and the contributions of the reviewers are gratefully acknowledged. Volume II Appendix 4 of this report contains the list of reviewers.

DISCUSSION

Throughout the course of this study we have made every attempt to coordinate our efforts with the National Park Service, local town selectmen and engineers and engineering firms with a knowledge of the shoreline processes in the Cape Cod area.

The land encompassed by this report, although not owned entirely by the National Park Service, is within its boundary. The easterly shore of Cape Cod has experienced serious erosion over the years resulting in loss of valuable land and structures. Many more structures are now in danger of being lost in the near future if they are not moved. This study was undertaken to determine if there is an economical, technically or environmentally feasible plan of improvement or protection that can be developed and implemented to prevent or retard the erosion problems along this shoreline.

Seven alternative structural and non-structural plans of improvement were considered and evaluated during the course of the study, and all were found not to have any economic justification for federal participation or cost sharing. The non-structural measures such as dune restoration and planting, grass planting in established areas, controlled beach access for bathers and vehicles etc., were considered for implementation by the towns and National Park Service and could ultimately assist in reducing this erosion of the dunes and backshore areas.

The majority of the people recognize and respect the natural erosion process taking place along most of our shoreline. At one time or another they probably have seen the results of a severe northeast storm and what it can do to beaches, homes and backshore dunes located within the coastal zone. Although these forces are readily seen, their magnitude and impact is difficult to understand and control. Erosion created by man, although not as great or as devastating as that of nature, contributes to this erosion process. A better understanding by everyone who frequents the seashore of the natural processes of erosion and accretion is essential to preserve the shore. This end can and should be accomplished through a well-organized educational program that will be interesting as well as informative. Concerned citizen groups in each town should conduct workshops and develop other educational programs to educate people in the value of preserving the dunes and beach grass and their value with respect to erosion control. Grass planting and dune stabilization programs should be planned on a regular basis with annual maintenance, as necessary, for areas subject to serious natural and man-made erosion. Breaches in dunes should be closed and planted, additional controlled access ramps, stairs, etc., from parking lots at popular recreational areas should be provided and maintained regularly to assure the healthy growth of dunes and beach grass. Fertilization of planted areas should be undertaken to assure healthy growth and reproduction of new and existing areas. If possible, plants that produce natural fertilization such as nitrogen should be planned in new planting areas and areas already established. Information on types of plants, proper planting and fertilization techniques are available from federal and state agencies. Many of these agencies are familiar to people on Cape Cod and a request to them for assistance would be welcome.

In our meetings and discussions with the National Park Service, they are ready and willing to cooperate in this matter. They already have several programs underway to try to determine the best method of retarding the erosion along the outer Cape. If agreed upon, the National Park Service Information Center, where millions of tourists visit annually, could be used to display and show educational literature and possibly a brief film on the reasons everyone should assist nature in her effort to resist erosion and preserve this area for future healthy recreational use.

RECOMMENDATIONS

The Division Engineer recommends that no beach erosion control project be adopted by the United States for the easterly shores of Cape Cod for providing protection against erosion from storm-driven winds, waves and tides because of the lack of economic justification.

The Division Engineer does recommend that local interests consider the need to implement non-structural erosion control techniques in accordance with the suggested methods discussed in this report. Seriously eroding areas of the shore, problem areas and potential problem areas should be monitored frequently with consideration given to the following:

1. Beach restoration by the direct placement of suitable sandfill and grass planting with fertilization.
2. Periodically nourishing these and other areas as needed to insure protection of backshore structures, sands and dunes.
3. Develop an educational beach erosion control program acceptable to all levels to explain the natural and man-made erosion process thereby developing a better understanding and respect for these erosion processes.

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Colonel, Corps of Engineers
Division Engineer

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